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ABSTRACT

Details are provided about the Audiographic Learning Facility, a pilot system for remote conversational instruction and learning developed by the School of Information and Computer Science at Georgia Institute of Technology. The report describes how learning materials, stored and reproduced in the form of a graphically supported narrative-lecture/blackboard presentation, are modularly structured into learning units which are randomly accessible via telephone from student stations. Further information is supplied on the objectives pursued by the development of the Facility, its design characteristics (learning materials, hardware, and control software), and its use for learning in a conversational mode--replacing live classroom in undergraduate and graduate education. (Author/PB)

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THE AUDIOGRAPHIC LEARNING FACILITY: OBJECTIVES AND DESIGN

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VLADIMIR SLAMECKA
Project Director

ABSTRACT

The Audiographic Learning Facility is a pilot system for remote conversational instruction and learning, developed by the School of Information and Computer Science, Georgia Institute of Technology. The learning materials, stored and reproduced in the form of graphically supported narative, lecture/blackboard presentation, are modularly structured into learning units which are randomly accessible via telephone from student stations. The report describes the objectives pursued by the development of the Facility; its design characteristics (learning materials, hardware, and control software); and its use for learning in conversational mode, replacing live classroom instruction in undergraduate and graduate education.

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I. INTRODUCTION

A major area of concern of the Science Information Research Center, a research program of the School of Information and Computer Science established in 1967, are research issues pertaining to information transfer in science. The process of communication in science, which has been of some interest for several centuries, has become during the last 15 years an issue of national concern, triggered by a fear that its effectiveness may be decreasing. Underlying this concern is the realization that science information and "knowledge" in general are a national or social resource.

Research has responded by a vigorous investigation of the process and tools of science communication. Perhaps because of the coincident development and deployment in the same period of time of a new information processing technology, these investigations have been dominated by efforts seeking to take advantage of the power of digital computing devices, by applying them to perform automatically many of the symbol transforming functions which occur in the process of science information transfer. The key characteristics of information processing automata - their memory and programs - have prompted concommitant research into, respectively, the description and organization of information, and the development of computable process algorithms. A host of collateral problems, brought along by the constraints of the new technology, also had to be dealt with: the design of languages for communicating with automata, uniformity and standardization of techniques and products, work organization and management, and other.

The research and development effort in science information transfer has been guided by the vision of Memex (Bush, 1947) and fostered by an exciting new technology. Its major visible product, now in a finishing stage, are large "banks" of descriptive information and data stored in electronic form. There is no doubt that the development of these complexes of bibliographic information, programs and technology, called "science information systems", is consistent with the direction of development of the entire information industry - the establishment of computerized information utilities and networks of different types - although many significant aspects of these systems remain to be studied.

meaningful design of science information services. Thus while we can superficially describe the information use of learners and teachers as "habits" caused or affected cumulatively by the environment and practices of the education establishment, the absence of tested theories describing the information process called human learning makes it most difficult to determine what is an effective or optimal design of information services. Instead of expecting to feed science information into the highly transitive and volatile contents of live classroom instruction and study, the preferred mechanism therefore is to first "fix" the learning materials temporarily in time. There is little doubt that recorded learning materials (textbooks, instructional films, etc.) are a solid client of science information services.

Effective use of science information in education thus appears predicated on the existence and availability of external, manipulable "memories" of learning materials. Fortuitously, education has recently also recognized the promising utility of such memories, and has begun to develop them as components of various "learning systems". The motivation of these efforts is different although not unrelated to the reasoning developed above; its principal argument states that progress in the understanding of the process of human learning may depend on the availability of such recorded memories of learning materials, for only through their use can research in education stimulate and test theories of learning, and reproduce empirically obtained results. The possibility to operate on large data banks provides education with the same promise and excitement as it does the social sciences and medicine - the potential of developing an empirically verified scientific foundation.

Given a suitably designed memory of learning materials for supporting the process of instruction and learning, it is possible to envision a mechanism making available to this memory the contents of scientific information systems as one of its principal inputs. The implementation of such a mechanism, illustrated in Figure 1, depends on the technical and economic feasibility of automatic or semi-automatic mapping of the contents of science information banks into the bank of learning materials. In turn, such a mapping is determined by the design characteristics of the latter bank.

The following chapter of this report discusses questions appropriate to the design of learning systems acceptable for this purpose, and it outlines the principal design objectives of the Audiographic Learning Facility being developed at the School of Information and Computer Science, Georgia Institute of Technology, for studying the expanded utility of science information systems in education.

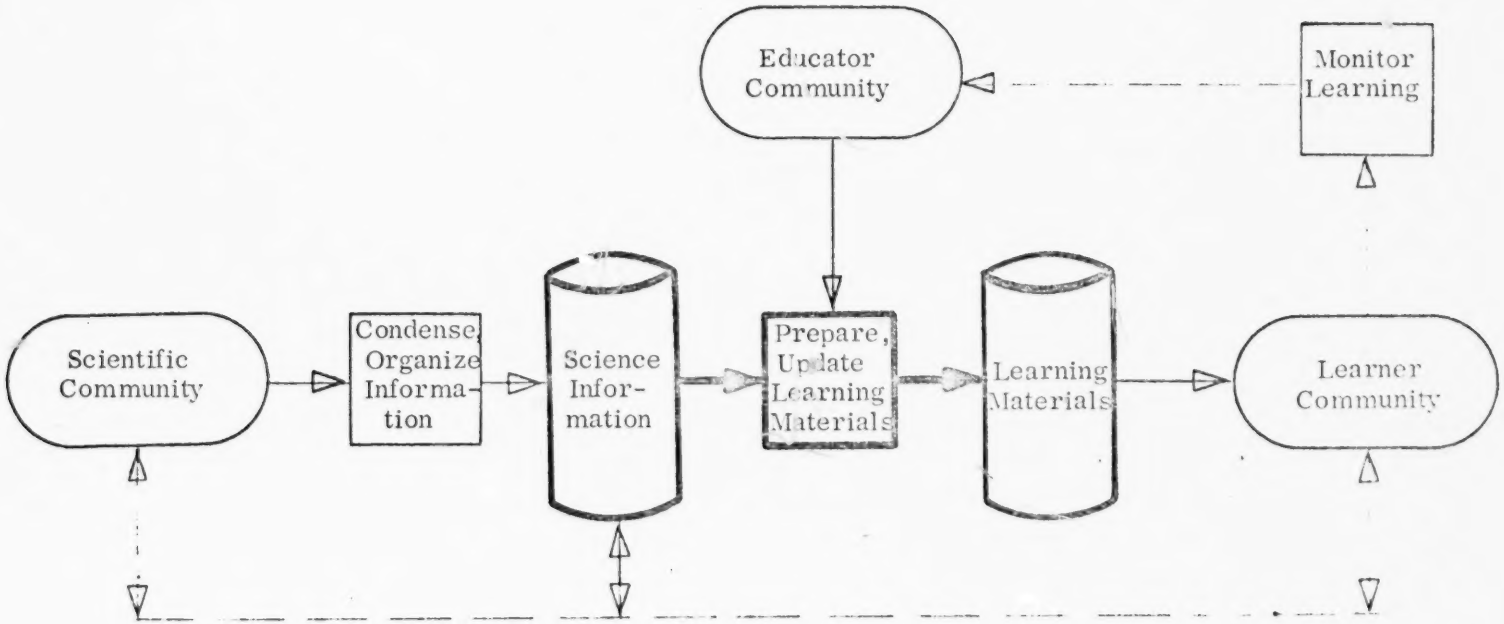

Fig. 1. Utilization of Science Information in Learning Systems

II. DESIGN CONSIDERATIONS AND OBJECTIVES

Conceptual redesigns of traditional educational systems and practices are being advocated today with exceptional vehemence and frequency. The impetus behind proposals for new designs is the desire to alter or abandon certain characteristics of present systems and practices which are shown to be inadequate. These designs emanate from the changing social objectives of education at the national level, shifting from an emphasis on mass education to that on its quality and relevance; and they acknowledge an increasing insight into the process of human learning and into significant differences among individual learners - differences which present-day education does not observe. Contributing to the arguments and proposals for educational changes are several groups of advocates: education researchers concerned with the efficiency of the process and mechanisms of learning; applied scientists and engineers developing new uses for information processing technology; and political and social scientists concerned with socio-economic objectives and planning.

This section reviews briefly and selectively certain positions of these advocates, with the intention of clarifying the desirable attributes of learning systems design. (The phrase "learning systems" denotes technology-aided instruction/learning in which the learner interacts with organized learning materials stored in a "memory".) Following a statement and discussion of such design objectives, this section examines in their light the adequacy of the main categories of recently implemented or proposed technological approaches.

Models of Learning

It is taken for granted that many of the constraints of present-day education systems would be relaxed with the successful development of an economical inanimate tutor capable of instructing and guiding individually learners in a manner similar to the interaction between the student and a live teacher, and substantial efforts have been expended in the past decade on the development of such "teaching systems".

Invariably, the attempts to construct inanimate tutor systems seek to simulate the interaction of human learners with their teachers; toward this end they develop and utilize various "models of learning" which abstract from and describe such interaction. Figure 2 shows an example of a model of human learning.

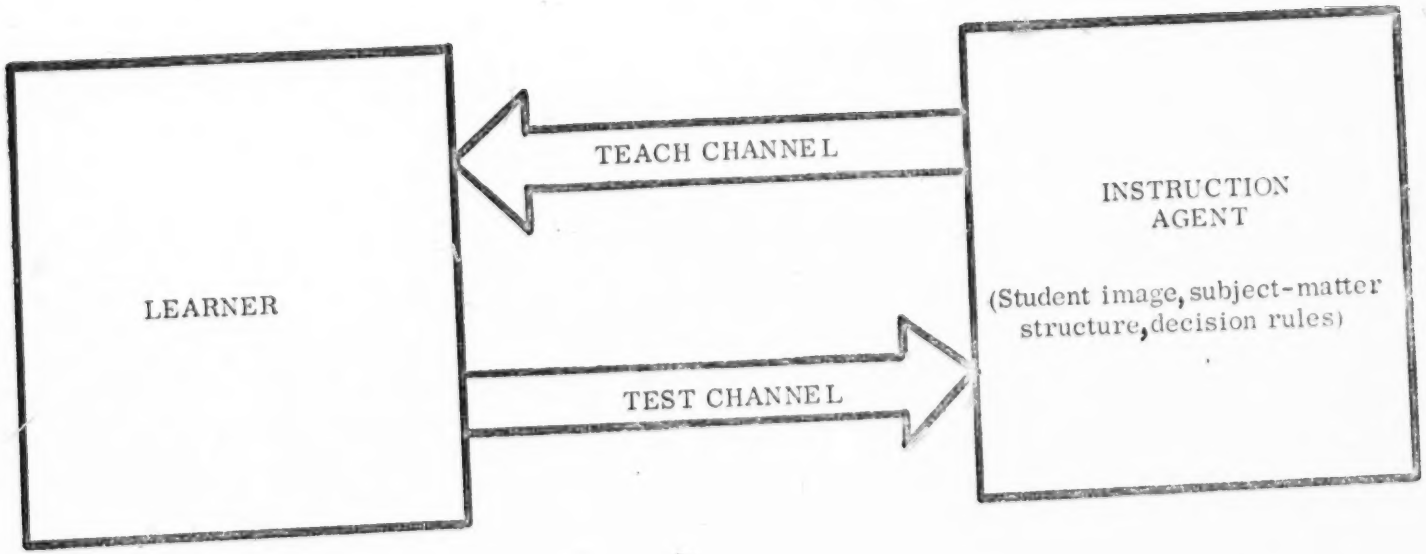

Fig. 2. A Model of Learning (after Kopstein and Seidel, 1970)

The procedure of constructing empirically models of human learning is discussed elsewhere (Pask, 1970). The typical model sees the learner drawing on a subset of knowledge organized and stored in an inanimate "memory"; the nature of this interaction between the student and the store of learning materials is determined by the tutorial abilities of the system. Depending on these abilities, models of learning are distinguishable by their power. In the order of increasing power and complexity, models of learning have been classified as feedforward, feedback, adaptive, and conversational (Pask, 1969). The powerful conversational model depicts the student as a self-organizing system viewing the human mind as a processor of procedures operating on information structures.

This view of the process of human learning requires a consideration of three variables which interact in it: goals, procedures, and information structures.

Learning Goals

Educational objectives have been classed to three categories: the cognitive, the psychomotor, and the affective (Bloom, 1956). The cognitive objective refers to the recall of knowledge and the development of intellectual abilities; the six such abilities identified include knowledge, comprehension, application, analysis, synthesis, and evaluation. Psychomotor objectives refer to manipulative skills; affective objectives to the development of values and attitudes.

To be useful, learning goals are often given in operational terms describing the terminal behavior sought; the process of learning is thus frequently described as "the modification of behavior in the light of experience". The following formula has been suggested to describe goals operationally (Mager, 1962):

1. Identify the terminal behavior by name;
2. Define the desired behavior further by describing the important conditions under which it will be expected to occur;
3. Specify the criteria of acceptable performance by describing how well the learner must perform to be considered acceptable.

A program of education invariably involves a hierarchy of goals set up to attain particular educational objectives. The organization and sequencing of this hierarchy of goals is not independent from either learning procedures or certain structural properties of knowledge.

Learning Procedures

Experience clearly attests to differences in the procedures in which humans learn:

> "Students...differ not only in their intellectual capabilities: some students like to proceed from the general to the specific, while others like to proceed from the specific to the general; some students refuse to pay attention to details before they have acquired an over-all view of the subject, while others cannot see the forest before having examined in detail each tree; some students learn by going over materials several times in increasing depth, while others prefer to examine one detail at a time." (Fano, 1970)

Various classifications of learning experiences have been suggested. One of them (Bruner, 1966) distinguishes experience ranging from direct to highly abstract, and identifies three modes of learning: the enactive, the iconic, and the symbolic. Another review (Cagne, 1965) defines eight different types of learning, each requiring different learning conditions. Various information processing capabilities of the human mind have been recognized: naming, differentiating, classifying, and generalizing, and a suggestion advanced that the thinking process can be described, measured, and simulated as a comparison-performing process; in this view, learning is "an ability to distinguish between similarities and differences and an ability to temporarily remember the results of some of those distinctions" (Currie, 1970). These hypotheses or axioms describing the presumed behavior of the human mind are only partially useful in the design of inanimate tutorial learning systems.

In order to be able to help a student to learn, the human teacher must have "in his head a reasonable model of what is in the pupil's head" (Minsky, 1970), a model which the teacher develops on the basis of information derived from his interaction with the student. The human teacher has only an indirect evidence of the procedure or procedures employed by the student, indicated by the sum of the student's relevant sensory outputs which the teacher must first interpret, then respond to. An inanimate teaching system invariably receives less information feedback from the student than a live private tutor (for example, it does not "see" the student's facial expression, or "understand" the mood of his voice); on the average, however, the learning system can receive more feedback information per student than a live teacher in a classroom setting.

The process of learning is at least in part a semiotic process, a necessary condition of which is the ability of the learner to receive signs via appropriate physical receptors, and to interpret what the signs signify. Various sign vehicles presuppose different receptors, and particular receptors affect the ability of the recipient to interpret signs; for example, many people can read music easily but few develop an absolute ear. Different learning modes emphasize different signs, sign vehicles, and sign receptors, with the symbolic mode being the most demanding. The choice of particular sign systems is of importance insofar as it affects the ability of the interpreter to recognize the meaning (significance) of signs.

A detailed understanding of the learning procedures of the human mind is beyond the state of current knowledge; and given the complexity of the problem which must include psychophysiological, biochemical, and environmental variables it is unlikely to be immediately resolvable. In the absence of such an understanding at a microlevel of human symbol manipulating procedures, the animate or inanimate tutor resorts to heuristic operations by devising goal-seeking strategies which operate along selected paths in the organized store of learning materials. The attainment of a particular learning goal then is a function of the amount of relevant information available, the form (signs and sign vehicles) in which it is available, and especially of its organization.

Structure of Learning Materials

For transmission, information must be organized according to some rules which can accomplish the goal of the transfer process; the rules of natural language, for example, are necessary to effect human communication. Similarly, organization of knowledge according to some rules is indispensable to effect the process of learning. The structure of a set of learning materials then is a configuration of elements of knowledge and their relations necessary to a given learning goal. As was shown above, the structure is not independent of the goal of learning and of the learning procedure.

The structure of a subset of knowledge has two important parameters: scope and depth. Scope refers to the range of elements of knowledge grouped together and related with respect to a given denominator or goal. The denominator may be an agreed, intrinsic attribute of the subset of knowledge, such as the carbon molecule to organic chemistry; the goal usually is an extrinsic denominator, e.g., the mission to "abolish smog". The depth parameter refers to the relative

level of difficulty of particular elements in a given subset of knowledge; it is definable only in terms of other elements of knowledge which are necessary and sufficient for their understanding. (Slamecka and Zunde, 1967)

Structures of learning materials developed in the past range with respect to both scope and complexity. Figure 3 illustrates the gross structure of a base for a four-year undergraduate curriculum, elements of which can be successively exploded - theoretically to the level of single concepts or even sentences, such as instructions to cook frozen vegetables or solve a quadratic equation. A structure is implied in any programmed instruction sequence, whether it be at the level of Figure 3 or in training to perform a simple task. The visible level of complexity (the density of the network of relations among the elements of knowledge) in existing structures of learning materials is usually low, for reasons which are easily understood. A deep structure for a large body of knowledge (such as in Figure 3), exploded to show the relation links between any two simple concepts (e.g., "domain of a Boolean function" and "minimal transistor circuit") could be extremely complex.

The learning procedures by which one would optimally acquire this knowledge are not well understood, so that particular learning goals might be reached by a large number of different paths through the network. It is thus not inaccurate to say that in today's education we transmit areas of knowledge by having only a gross and intuitive understanding of their optimal structure; nor is it an exaggeration to emphasize the crucial importance of the notion of structure of knowledge to further research into the nature and process of human learning. The verification of our current intuitions about the various types of learning (as well as about other possible types of learning) depends on the existence of large, adequately structured knowledge banks.

In the evelopment of learning systems, thus the structure of learning materials must be explicit. Given a particular learning goal or goals, and ideally postulating a certain type of learning, the structure of the learning materials is developed in the form of a "list" structure - an information structure in which each element is linked, as a minimum, to any and all immediately preceding nodes which are necessary and sufficient for that element to attain or contribute to its goal. Since a large body of learning materials will in all likelihood serve several or many goals, any one element of that body of materials may be a necessary, desirable, or alternate component of more than one goal-seeking learning programs; such element will then lie on more than one list. The complete information network

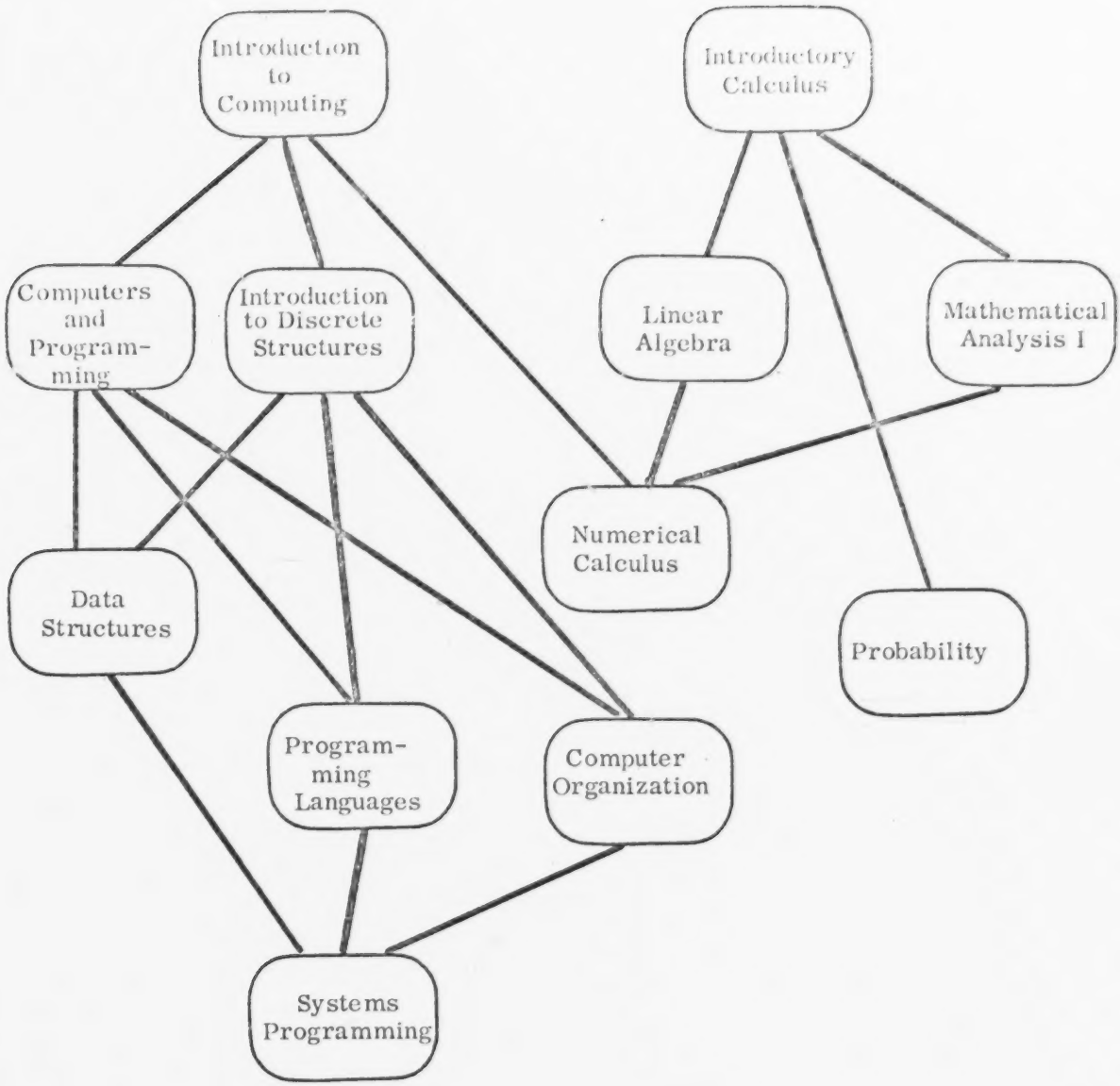

Fig.3. Suggested Structure of Basic Learning Materials in Computer Science (after ACM, 1968)

becomes a multigoal, multilevel system. Its design is somewhat like the design of a generalized data-base structure capable of accommodating unanticipated operations on the logical relations of the data contained in it, except that other considerations must be added (since the content is descriptive information, not data): the style of presentation, the semantic consistency of the materials, the minimum and maximum length of an element, etc.

Design Objectives

To reiterate: the purpose of this effort is to design an operational instruction/learning system suitable for absorbing the contents of science information banks. Clearly, unless the system is operational and actually used, the goal of this effort will not be met. In the light of this constraint, and following an intensive study, highlighted above, of the systems, methods, accomplishments and aspirations of human education, a set of four primary attributes was formulated for the design of an instruction/learning system for science education (Slamecka, 1969). These attributes, or design objectives, are briefly discussed below.

OBJECTIVE 1: The system must utilize effectively man's capability to receive information.

The principal receptors used symbiotically in human higher learning are his eyes, ears, and hands, and there is substantial evidence that many of the factors involved in learning (e.g., memory retention, concentration and attention) depend significantly on the choice of receptors employed. Education systems using principally visual information (alphanumeric and graphic) fail to exploit the versatility of man's input devices, as do systems relying on audio instruction. A realistic educational system must, as a minimum, approximate the human tutor who transmits information in both visual and audio form.

In visually transmitted information, the role of graphics (as contrasted with alphanumeric symbols) cannot be underestimated, as has been shown by a recent study of the relative amounts of textual and graphic materials in the published literature of various disciplines (Olsen, 1969). The study does indicate, however, that for some subject fields (social sciences, physical and natural sciences, engineering, agriculture, trade) line illustrations, charts, graphs and tables are

adequate to convey the bulk of the graphic messages. On the other hand, religion, linguistics, and especially the fine arts and literature rely heavily on using full- and half-tone graphics; less than 5 percent of all graphics was in color.

Man also has the ability to receive information concomitantly through more than one input receptor, an ability which education exploits in audiovisual (classroom and multi-media) presentation but loses in the medium of static recorded materials (e.g., a textbook). The conjoint transmission of audio and graphic information or symbols is desirable in both skill and cognitive learning, and especially so in the symbolic description and explication of processes, procedures, operations and programs.

OBJECTIVE 2: The system must be general to suit a broad variety of educational objectives of society.

This objective of the design of a learning system is given by the condition that the system be operationally viable and actually used, a condition without which the objective of developing a new market for science information would be less than realistic. The objective then refers to the utility of the system for accommodating learning materials of many subject areas, for varying learning goals and objectives, and for different levels of education. The implicit question in this requirement of what is the reasonable and the maximum volume of learning materials the system design must support must not be interpreted as requiring that all these learning materials, and all these educational needs and goals must be met from one single, homogeneous, physical facility, whether centralized or interconnected by a network. Rather, the objective is to design a vehicle so flexible that its size and content can respond to the educational needs and objectives perceived and defined by society and its many and varied elements.

OBJECTIVE 3: The system must support individual learning in a conversational mode.

The requirement that the system accommodate the learning goals and procedures of individual learners is a sine qua non. Stated in other terms, this design objective requires that the system be able to

serve learners individually, to suit their own pace, their learning goals, that it be available at the time of their convenience, and that it permit the use of different learning strategies. (Significantly, however, this requirement does not obviate the possible use of the system in group learning; one should not assume that all learning must be conversational, or that the group atmosphere does not have positive effects on learning, or that in some circumstances economic reasons may render group learning not only preferable but more cost-effective. The ideal system should be flexible to permit a switching from single to collective learning modes.)

Of the various models of learning, only the conversational system comes powerfully close to simulating the student-tutor interaction. The object of this interaction between a tutor and a learner is, essentially, to reduce the uncertainty of the learners in two areas: that concerning his understanding of the information being learned, and that concerning the next step or steps toward his learning goal. In a face-to-face contact with his tutor, the student reduces the first uncertainty by one or more mechanisms, as follows: if he doubts that he understood the material, he asks for its clarification (the tutor obliges by one or more of the following techniques: he repeats the material verbatim; he presents the material using an alternate wording; he offers an example); if he (or his tutor) wishes to determine whether he has understood or learned the material, he tests himself by solving a problem or answering questions. Based on his confidence that he has (or has not) learned the material, the tutor recommends the next step to a more advanced (or repetitive, remedial) material.

The most advanced function of the human tutor is his ability to diagnose the reasons for the student's failure - reasons which may well lie outside the learning material - and to suggest an effective, efficient remedial procedure. While it is not immediately clear that the average human tutor is highly competent in this respect, the simulation of the diagnostic functions in learning automata is cumbersome. More elegant approaches appear to require an efficient semantic interpreter of human language, a "memory" approaching that of the student and his tutor, and other facilities.

OBJECTIVE 4: The system must be economical.

Few axioms have been demonstrated more clearly in recent years than the argument that widespread applications of educational technology are unlikely unless the educational community can afford their cost. This realization is tempered only to the extent that we are not in agreement as to the cost which the educational community can afford - a disagreement given partially by the fact that the educational community itself is not consistent or comparable (for example, the values of public school education and of industrial training are not comparable in terms of the same cost criteria), partially by the inability so far to develop generally acceptable measures of cost and benefit in education. What is then the meaning of "economical"?

Attempts to assess the economics of educational systems have proceeded invariably by comparing their actual or presumed cost with the actual or presumed cost of traditional education, usually in units of cost expressed as cost/student/hour. The difficulties encountered in arriving at creditable cost figures are amply documented (Kopstein and Seidel, 1967). Despite the tenacious nature of these estimates, the cost ranges for the more powerful (conversational) systems are sufficiently high to indicate that these systems are not competitive at the present time. In theory, significant reductions per unit cost may be expected with very large systems used at capacity (Bitzer and Skarpedas, 1968), and it is usually from this base of regional or national budgets of education and training that such networks are justified (Seidel and Kopstein, 1970).

The expectation that educational, technology-based systems will become widely used when supported by the Federal and State governments is fraught with uncertainties, however. Socio-political factors in the United States, where authority over education is vested in local communities, appear to argue against the acceptance of educational systems which can be economically justified only on a regional or national level (Grayson, 1970). The rate at which these systems can effectively replace traditional modes of education is also questionable: they are not merely introducing a new teaching technique but are altering the entire social system of education. Again, the often-advocated

partnership of education with government and business still lacks even realistic models, and it should not be assumed that industry or government will be enthusiastic about a national educational system all resident in 430 large computer centers (Carter, 1969). These and other reasons as well as analogous precedents (e.g., proposals to build a few atomic power super-stations to provide the nation with low-cost desalted seawater) suggest strongly that the ultimate "system" shall develop gradually and slowly, unless the economic viability of educational technology applications changes rather drastically.

The cost of learning systems consists of two major components, each having different cost characteristics: the physical facility (hardware and programming software), and learning materials. When hardware is the major cost item in the physical facility, the cost of the facility increases nearly linearly with its increasing capacity; in other terms, the cost per student hour is nearly invariant of the size of the facility. Since this relationship obviously holds only above a certain minimum size, it is of much interest to find, for any proposed system, this minimum configuration above which the facility cost per student-hour will not increase appreciably. The cost of learning materials on the other hand, has the opposite characteristic: it decreases with the increasing number of learners. Implicit in this relationship is the notion that the totality of knowledge is a societal or national resource, and that it is in the interest of society to have this resource vended and disbursed at a price which is not exorbitantly out of proportion with the over-all cost of producting and maintaining it. Figure 4 illustrates these cost relationships of the facility and learning materials.

The preceding considerations indicate clearly that in order to ascertain an acceptable cost for implementing - today - an educational system it is not helpful to cite a figure of unit cost which is predicated on a very large user population; as reasonable as the unit cost may be, what determines the feasibility of implementation is the availability or acceptability of the total project costs. The general approach by which the School of Information and Computer Science arrived at a meaning of the term "economical" was to ask simply: What is the amount of money a customer is able and prepared to pay for a learning system having

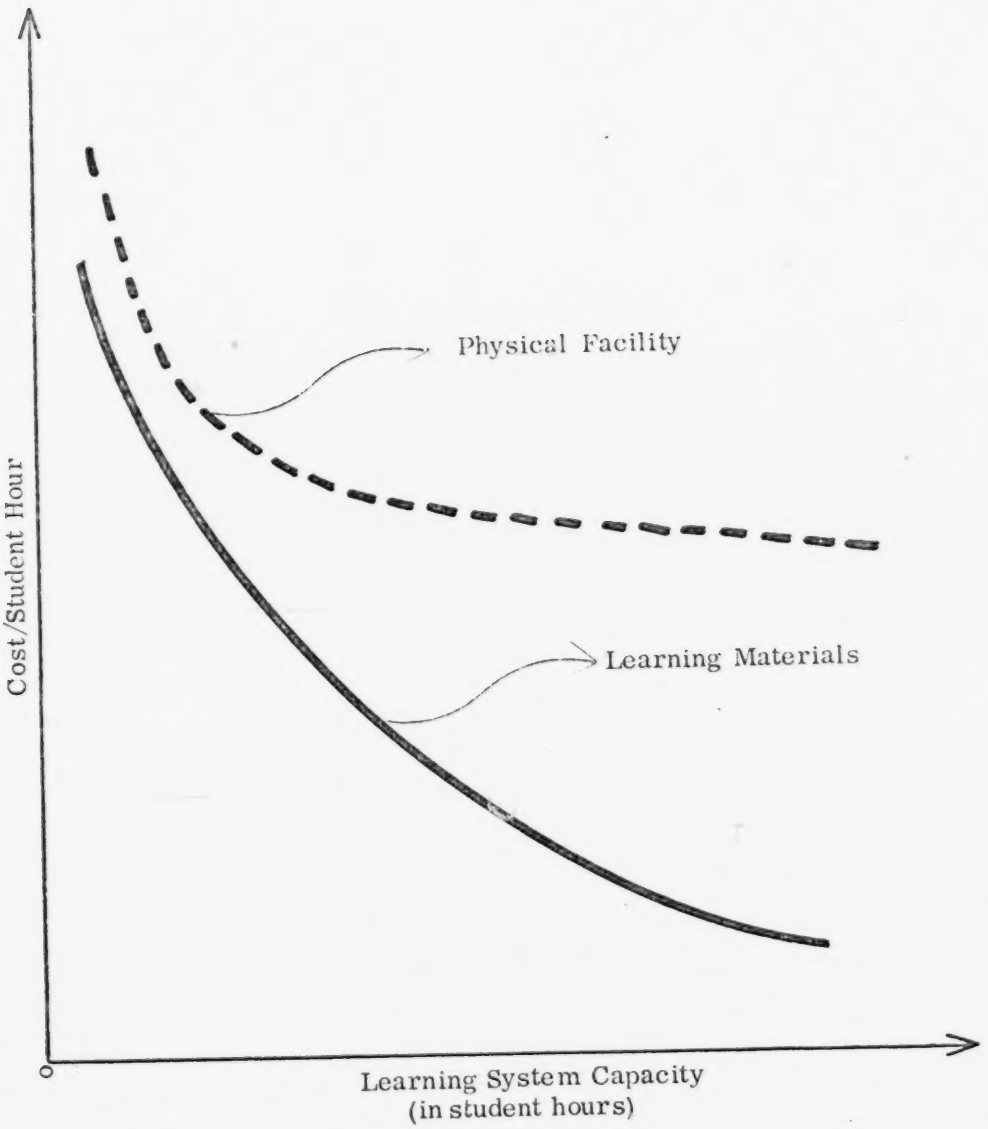

Fig.4. Relationship of Cost Elements in Learning Systems

specified performance and properties? The following example illustrates this marketing approach to educational cost analysis:

Assume an academic department which offers, each academic quarter, 20 sections of a particular subject sequence (say calculus). Each 30-hour course section handles 25 students, for a total of 500 students per quarter (2,000 students per calendar year) and 60,000 student hours per calendar year. At a full-time teaching load of 4 courses per quarter, an equivalent of five faculty members are assigned to this course load. Given an average faculty salary of $20,000 per 12 months (which includes the cost of support staff), the direct annual cost for offering these courses is $100,000 in Personal Services.

Assume now that the department chairman is prepared to offer the same courses via a conversational teaching system, providing this can be done without increasing his budget. Assume further that he has decided to retain two of the five faculty members to continue as full-time tutors in this subject matter, and to reassign the remaining three teachers and their support staff; this releases in his budget a sum of $60,000 which he is prepared to apply to cover the full annual cost of the teaching system - hardware, software, communications charges, operating expenses and author royalties. (We ignore that he will have certain one-time start-up expenses.)

We calculate that the total cost for the system and its operation, if amortized over a five-year period, must not increase $300,000. Since the cost of student terminals in a conversational system can be substantial, it is of interest to determine the minimum number of terminals required to teach this student load in an individual learning mode. Assuming 2,000 working hours in a calendar year (250 eight-hour days), the minimum number of student consoles serving an annual load of 60,000 student hours is 30. There is such reason why at times some students might prefer to learn in small groups using an appropriately designed student terminal; in such a case, less terminals would suffice.

Cost analyses of this type, as superficial as they may be, indicate a pragmatic ceiling for operating costs of realistic educational systems. Immediately, one can draw various conclusions. For example, if "it appears both internationally and in the United States that an operating budget of approximately $250,000 to $300,000 a year is necessary merely to maintain facilities [of large-scale CAI centers] in operation" (Seidel and Kopstein, 1970), such facilities clearly do not serve our objective of economic feasibility, consequently narrowing the range of devices which

can be considered. If the learning materials were procured or purchased at a cost of, say, $500.00 per lecture hour (total cost of five 30-lecture courses is $75,000, or 25 % of the total budget available), the annual operating costs associated with the physical facility cannot exceed $15,000. Given the lower bound on the cost of conversational terminals to be not less than $1,500 (or $9,500 per year for 30 terminals amortized over five years), it is possible to derive rather accurately the permissible and available cost items for control hardware, memory, communications, maintenance, and operator costs. This approach, while it obviously does not guarantee a widespread acceptance of learning systems, should be able to pre-empt the argument of economics which has been frustrating a more rapid application of information technology to education - provided it is possible to design educational systems within the economic constraints so determined.

Adequacy of Existing Approaches

Evaluation of existing or proposed learning systems rapidly confirms that in the light of the four design objectives stated above, generic and economically viable, marketable approaches to the conversational simulation of learning remain wanting.

The technologies which are contributing to the design of educational systems and devices are impressively diverse, even though the signs they process and transmit are ultimately received in two forms only: visual and audio. There exists a division of these technologies, traceable to their historical development, along the two forms which they process and store information, the digital and the analog. The digital technology relies so far on electronic and electromagnetic principles; the analog technology can operate on chemical, electromagnetic, and electronic principles. The major systems applications in educational technology which have thus evolved along these lines fall into four categories as follows: 1. Digital, exemplified by computer-based learning systems; 2. Analog-magnetic, exemplified by Dial-A-Lesson systems; 3. Analog-chemical, exemplified by film; 4. Analog-electronic as exemplified by ETV (Educational Television) and EVR (Electronic Video Recording).

Table 1 summarizes the present-day capability of these four system categories to meet the previously stated design objectives.

Technology	System Examples	OBJECTIVES*			
		1	2	3	4
Digital	CAI	NO	YES	YES	NO
Analog-Magnetic	Dial-A-Lesson	NO	NO**	YES	YES**
Analog-Chemical	Film	YES	YES	NO	YES
Analog-Electronic	ETV, EVR	YES	YES	NO	YES

*See pp. 12-18 of this report

**The opposite holds for the PYRAMID system

Table 1. Evaluation of Existing Learning System Types

The major conclusions to be drawn from Table 1 indicate that present-day applications of such analog media as film, video tape, and EVR meet all objectives except one: they do not permit conversational learning.

Conversational computer-based systems, several of which are in advanced development (Alpert and Bitzer, 1970; Kopstein and Seidel, 1969; Atkinson and Wilson, 1968) fail to meet the criteria on two counts: their high cost, and their inability to accommodate extensive audio materials.

Analog voice-storing educational systems, while attractive economically, have no elegant provision for handling visual data (alphanumeric, graphic or pictorial) except via separate attachments;[1] in their present state none of these audio systems is truly conversational, even though they do have provisions for remote control (Ofiesh, 1968).

The next sections of this report outline the design of the Audiographic Learning Facility developed at the School of Information and Computer Science in response to the four major design objectives. The facility purports to be a step in the direction of generic, economically viable, conversational learning systems capable of adequately simulating live interaction between a learner and his tutor.

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[1] In an interesting attempt to bridge the video/audio division in existing conversational systems, the Pyramid learning system (originally designed as a random access audio facility) has successfully combined voice and still-image frames in a remote control mode (AMPEX, 1969), although at a high cost.

III. THE AUDIOGRAPHIC LEARNING FACILITY

The Audiographic Learning Facility developed at the School of Information and Computer Science, Georgia Institute of Technology, is illustrative of a category of modular, technologically versatile learning systems conceptualized by the School in response to the four major objectives discussed in the previous section of this report. The major characteristics of this category of learning systems are as follows:

1. The learning materials are stored centrally in the system in two forms: visual and audio (to be called in this report "audiographic" materials). The visual form includes motion graphics - handwriting, drawing, etc. - synchronized with the narrative presentation, hence capturing in recorded form the spoken and graphic content of live blackboard lecture presentations.
2. The audiographic learning materials are stored in randomly addressable "learning units" of variable length. The logical structure of this body of knowledge is explicated via a syndetic apparatus which permits a variety of goal-seeking learning strategies - programmed (linear and branching) or random ("browsing") - to be implemented under the control of either the system (tutor) or the individual learner.
3. The conversational character of live tutor/student interaction is simulated by means of diagnostic self-testing coupled with variable strategy design, under the control of either program (tutor) or learner.
4. The physical implementation is possible using analog and/or digital technology, and either voice-band or broad-band communications facilities.
5. A range of modularly expandable system configurations is economic for a wide span of different learning requirements and market sizes.

The Audiographic Learning Facility of the School of Information and Computer Science is a prototype of a modest level and cost of this category of learning systems. The Facility provides four independent, on-line learner stations, each having at its

disposal 50 hours of learning materials in audiographic form. This body of knowledge, segmented into learning units which can vary in length from one to sixty minutes, is recorded on six 4-channel tape recorders. Through a combination of computer programs and system hardware elements, each learner station ("terminal") has the following repertoire of functions: stop, start, high-speed backspace and high-speed advance over single and multiple learning units, gain access, rewind, and disconnect. The audiographic terminal consists of a telewriter device for hard copy graphic output, and a Touchtone telephone for audio output and system control.

The hardware system of the Audiographic Learning Facility is shown in Figure 5. The remainder of this section discusses in some detail the three significant components of the Facility: the resource of learning materials, the hardware, and the control software.

The Rosource of Learning Materials[1]

The Audiographic Learning Facility has two main purposes: (1) to demonstrate and evaluate this category of conversational learning systems by employing it as a self-contained and major component of higher education; and (2) to devise and evaluate techniques for automatic transfer of science information into the educational progress. Since both purposes presume a substantial and diverse resource of learning materials, it is the intention of the School of Information and Computer Science to record in audiographic form and make available for individual or group learning a resource of learning materials consisting of undergraduate and graduate level subject matter areas, roughly equivalent to courses and course sections, in mathematics, logic, linguistics, information and computer science, information systems analysis and design, cybernetics, and similar. The recording of several of these subject areas has already been completed.

Simulation of a conversational interaction presupposes that the resource of learning materials consist of modular learning units, each unit ideally being oriented about a single, self-contained concept. For reasons of flexibility in retrieving and ordering concepts in any desired sequence, and due to the evidence of relatively short attention spans of students using learning systems, it is desirable that the

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[1] Dr. Gordon Pask, Visiting Professor, and Miss Margaret E. Dexter, Research Associate, have collaborated in the development of the concepts described in this section.

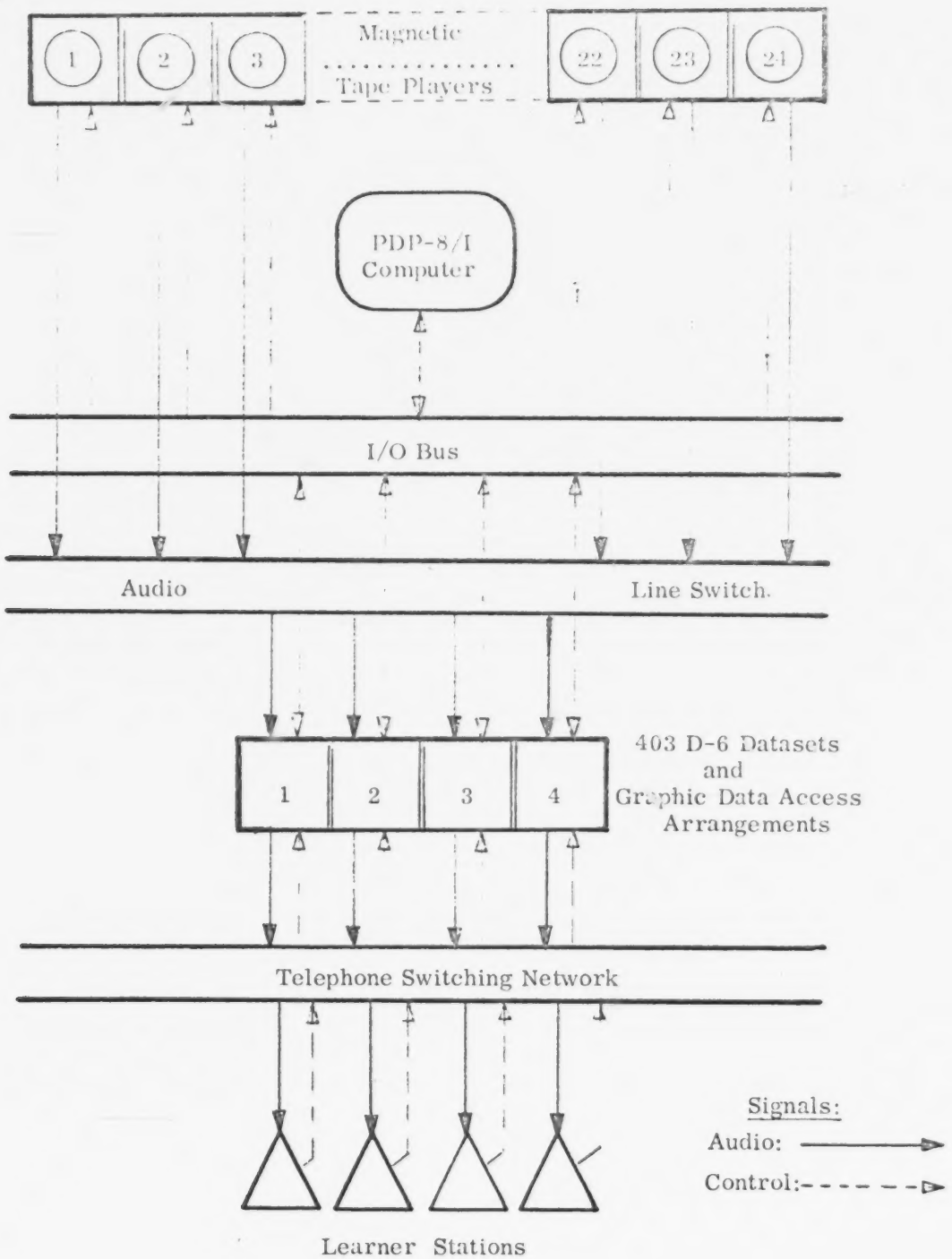


Fig. 5. The Hardware System of the Audiographic Learning Facility

learning unit be relatively short; although the Audiographic Learning Facility provides a variable length of one to sixty minutes, learning units tend to be in the five- to 15-minute range. The resolution of subject matter into learning units is one step finer than the preparation of course outlines: the instructor identifies the level of knowledge presumed for the subject matter area to be presented; he determines and describes one or more goals of performance or behavior to be acquired and demonstrated by the successful learner; and he proceeds to determine the concept clusters and individual concepts to be taught.

The structure of any subset of this resource of learning materials is identified with respect to two attributes: its membership in a particular learning goal or goals, and the learning dependency among the units comprising this subset of learning materials. While learning units are interrelated in may ways, the dependency relation is important in that it identifies, for a given learning unit, any and all necessary precedent units. The precedence relation may be conveniently represented by a directed graph which indicates, to any depth desirable, all of the prerequisite and alternate prerequisite concepts for each learning unit. Figure 6 illustrates this structure among the concepts pertaining to the area of sentential logic.

The syndetic apparatus which describes the physical, semantic and learning relation attributes pertaining to a body of knowledge consists as a minimum of four descriptors or pointers: 1. the address, which identifies the physical location of a learning unit; 2. the learning goal(s) which tags the learning lesson as a member in a particular goal-seeking strategy; 3. the precedent unit(s), which points to the necessary or alternate, immediately preceding lesson or lessons, subject to a particular learning goal; and 4. the subject(s), describing the semantic content of the learning unit. Other types of descriptors are, of course, possible and may be desirable. Such a syndetic apparatus is indispensable to the Audiographic Learning Facility for deriving, under program or user-control, individual learning strategies, and for producing a variety of learner- or tutor-oriented aids such as structural maps for a subset of knowledge, cross references indexes, etc. The apparatus will also be indispensable in the attempted symbiosis of science and learning information systems, as well as in studies of human learning which are contemplated with the Audiographic Learning Facility.

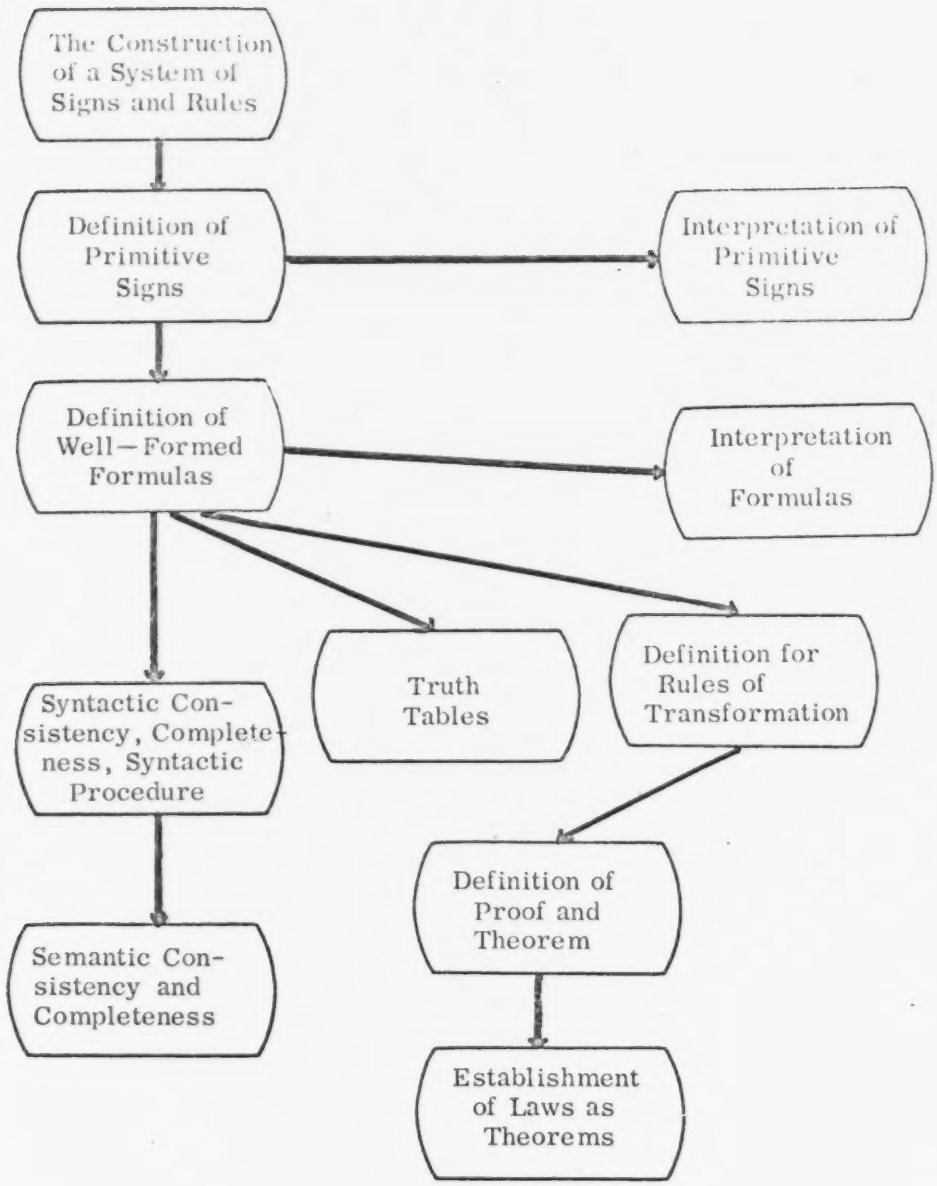

The Construction of a System of Signs and Rules
Definition of Primitive Signs
Interpretation of Primitive Signs
Definition of Well—Formed Formulas
Interpretation of Formulas
Truth Tables
Definition for Rules of Transformation
Syntactic Consistency, Completeness, Syntactic Procedure
Definition of Proof and Theorem
Semantic Consistency and Completeness
Establishment of Laws as Theorems

Fig. 6. Sentential Logic: Precedence Relations Among Learning Units

The Hardware System

The major components of the Audiographic Learning Facility are shown in Table 2. This section discusses the current status of development of the physical facility.

Table 2. Audiographic Learning Facility: Hardware

Number of Units	Device
24	Four-channel tape recorder
24	Recorder control register
4	Dataset control register
4	Graphic data access arrangement and telephone lines
4	Special data access arrangement
4	403-D6 Dataset and telephone lines
1	PDP-8/I computer
4	Victor Electrowriter receiver
4	Touchtone speaker telephone

PDP-8/I Computer

The configuration of the computer system which supports a broad range of R/D activities of the Laboratory of the School of Information and Computer Science is shown in Table 3. Of this configuration, the components which are actively under use with the Audiographic Learning Facility are the PDP-8/I Processor and 4,096 12-bit words of core; a Teletype console; the 250,000 12-bit words of disk; and 2 receive-only asynchronous data communications channels.

In addition to these standard components, special relay registers have been interfaced to the PDP-8/I. Each of these registers provides 12 single-pole, single-throw relays which can be addressed through a PDP-8/I device code and set ON or OFF, depending on the contents of the 12-bit accumulator. The registers are wired to provide controls for tape recorders and for the switching of communication lines. The computer commands related to the relay registers are CLEAR and SET. The CLEAR command addressed to a particular relay-register-device code causes all 12 of the relays to be set to a normally open condition; the SET command causes

Table 3. Laboratory Equipment List

No.	Units	Item Description
1	1	IBM 029 Keypunch
2	1	ASR-33 Teletypewriter on Dataphone Service
3	1	ASR-33 Teletypewriter and Anderson-Jacobs Acoustic Coupler operating on Dataphone Service
4	2	103-A2 Dataphone Datasets
5	1	403-D3 Touchtone Dataset with ASCII code converter and associated Touchtone Pad
6	1	Kodak 35mm Carousel Projector
7	1	Execugraph Sync-Sound Projector/Audio System
8	8	Sony Electronic Control 4-track Stereo Audio Tape Recorder/Player
9	1	Uher monaural, multispeed, Audio Tape Recorder/Player
10	1	Victor Electrowriter Transmitter
11	2	Victor Electrowriter Receiver
12	1	Digital Equipment Company PDP-8/I Computer with EAE, 8K Core Memory, 2 DEC Tapes, 4 A/D Converter channel, 3 D/A Converter Channel, Hi-Speed Paper Tape Reader and Punch, 2 PTO8's (300 band and 1,200 band), one DPO1-A Data Communications Channel capable of synchronous operation at 150, 300, 600, 1200, 2000, 2400, 40.8K, and 50K bit rates. 500K words of Disk and joy stick operated graphic storage scope (KV-8/I).
13	1	Motorola MDR-1000 Document Reader which operates at 1200 bps.
14	1	IBM 2741 Data Communications Terminal
15	1	INKTRONIC Printer
16	1	Sony TV Camera VCK-2100
17	1	Sony 1/2 inch Video Recorder AV3600
18	1	Setchell-Carlson 23" TV Monitor
19	1	Bolt Beranek & Newman 17" Analog Plotter (Series 700)
20	1	Tektronix 611 Storage Scope
21	1	Graf Pen 12"x14" Digital Graphic Input Device
22	1	3246 T Amplifier
23	1	Viking Stereo Cassette Recorder/Player
24	1	Sony Stereo Cartridge Recorder/Player
25	1	Digital Equipment Company Logic Laboratory

relays to be closed corresponding to accumulator contents. This simple design and command structure provide for easy programming of this stable device.

The register design allows the connection of any recorder output to any calling telephone.

Tape Recorders and Recording

The tape recorder model now in use is the SONY Stereo Tapecorder TC-666D; these solenoid-control units have been modified for remote control. Eight such recorders are mounted in two racks of four each, and operate under computer control. One additional tape recorder is used in the recording studio.

Audiographic recordings are comprised of two tracks of audio record signals. The left track contains frequency modulated signals generated by the position coordinates of the telewriter pen transmitter, and a reference signal used to record and correct signal distortions encountered in recording. The graphic information recorded on the left track is synchronous with the audio signal recorded on the right track. Individual learning units are separated on the audiographic tape by inter-record gaps.

The generation of audiographic learning materials allows for either independent or simultaneous recording of the voice and the graphic signals; if recorded independently, either signal can be dubbed in with the other track. Accurate timing is of importance in the generation of audiographic learning units, and also in the transfer or re-grouping of learning units from tape to tape. An editing facility has been outlined in response to these needs[1], and it is intended to implement it in the near future.

Data Set and Special Access Arrangement

The Bell System 403-E4 Data Set is designed to accept Touchtone signals and to convert them to a 10-bit, ASCII coded asynchronous character representation for transmission as a serial bit stream to a computer or any other business machine. Although this Data Set does not provide for voice answer-back or for switching from voice to data, it offers a standard data communications interface (EIA RS-232B) allowing it to operate through a standard PDP-8/I communications controller (PT08) as through it were a transmit-only teletype unit. The versatility and low cost of this combination of devices has led the School of Information and Computer Science to explore with Southern Bell and AT&T a circuitry design permitting voice transmission

[1]With the assistance of Dr. Gordon Pask, Visiting Professor of Cybernetics

with the 403-E4 operating in data mode. As a result, a special access arrangement has been implemented which permits the transmission of voice from the right output channel of the previously described tape recorder into the phone line servicing the 403-E4; while this voice recording is being transmitted, the 403-E4 Data Set will recognize and process a Touchtone signal generated by the user at the receiving end. Since the Touchtone signals can be recorded, control data can be stored on the audiographic recording which thus becomes an integral part of the Facility control system.

The special access arrangement has been in use since Summer 1969; a second unit will be installed in September 1970.

Graphic Data Access Arrangement

This unit is comprised of a standard Victor Electrowriter Dataphone Dataset and a specially designed and built Graphic Recording Compensator. The Compensator receives the output of the left channel of a tape recorder and removes the distortions which result primarily from the wow and flutter characteristics of the recorder. The corrected signals of the Electrowriter transmitter are then inserted into the graphics telephone line by way of the Electrowriter Dataphone Dataset.

One Compensator unit has been built and has been in use since March 1970. Six additional units are being constructed.

User Terminals

Group learning stations employ a Victor Electrowriter receiver and projection system, called VERB. This unit receives line graphics, transmitted from the left output channel of a selected tape recorder over a standard business telephone line, and project it on a standard size screen. Individual learner stations employ the Victor Electrowriter receiver without its projection unit. In addition, each learning station employs a second standard business telephone terminated with either a Touchtone dialing unit or a Touchtone pad attachment, and equipped with a speaker output.

The Computer Control Program

The role of the computer control program is to accept command information from multiple terminal stations, to translate commands into requirements, and to effect controls on the devices whose actions satisfy these requirements (Wright, 1970).

Command information is presented as a symbol strings composed of the (Touchtone) characters: 0,1,2,3,4,5,6,7,8,9,*,#. A meaningful symbol string is of the form *ddddddddd# where d represents any decimal digit. The minimum command string is *#; the maximum command string, *999999999#. A command string may contain only one asterisk and must be terminated by a parataxis; for instance, ***1*9# would be interpreted as *9#.

Command strings are of three categories: Movement Commands, Library Requests, and System Commands.

Movement Commands

Movement commands are of the form *0mddddddddd# where the zero indicates movement, m is either 1,2, or 3 and d is any decimal digit. The following strings have the indicated meanings:

*01# place the tape movement in continuous PLAY mode

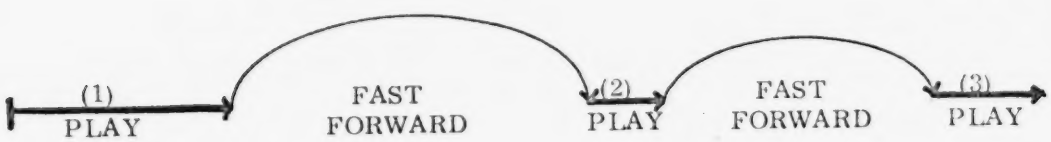
*02# place the tape movement in continuous FAST FORWARD mode

*03# place the tape movement in continuous REWIND mode

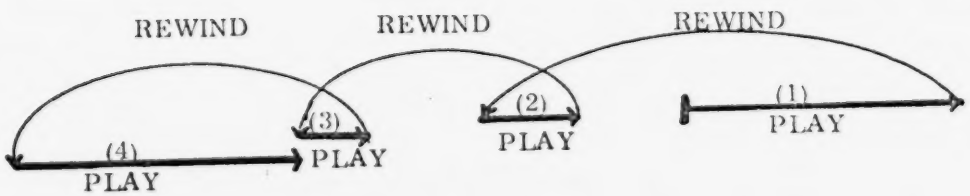
*# STOP the tape movement

Both a continuous and an interrupted movement mode are provided for the FAST FORWARD and REWIND commands. In the interrupted movement mode the tape motion is pictured below:

Interrupted FAST FORWARD



Interrupted REWIND



In the FAST FORWARD and REWIND command strings, the sum of digits d determines the number of interrupted movement units, since the program executes

$*0\begin{Bmatrix}2\\3\end{Bmatrix}$ dd...# as $*0\begin{Bmatrix}2\\3\end{Bmatrix}$ d+d+...#

Examples: *02123# means move FAST FORWARD six movement units

*03123# means REWIND six movement units

*02111# means move FAST FORWARD three movement units

*0211111110 # means move FAST FORWARD eight movement units

The STOP command *# stops the tape movement until a movement command is given.

Library Requests

Library requests are represented by a command string having the general form *1OOOO#, where O stands for the octal digits 0 through 7. These octal digits represent a learning unit address key; the latter is available to the user from a printed index. Using this data the control program identifies the tape on which the requested learning unit is recorded as well as the location of the unit on that tape.

System Commands

System commands, issued by Touchtone signals recorded on the audiographic tapes, separate and identify learning units. These commands are of the form *9OOOO#, where OOOO is the octal address key of the learning unit requested.

The number of system commands comprising an inter-record gap is approximately five. Since the Touchtone signal in a system commands endures for about one second, each such command uses seven seconds; thus, the inter-record gap is about 35 seconds long.

The computer control program is a highly modular program providing asynchronous operation of multiple users by virtue of its interrupt handling characteristics. In its present state the program will accept and manage simultaneous inputs from five user stations, any one of which can be assigned to any one of the 25 tape units. At present the control program does not provide, however, a user identification procedure; user activity accounting; audio response for informing the user of system conditions; and a means of knowing when a user has simply broken his telephone connection without following the prescribed termination procedure.

IV. THE AUDIOGRAPHIC FACILITY AS A CONVERSATIONAL LEARNING SYSTEM

Earlier in this report (Page 15) the two desirable characteristics of conversational learning systems were said to include (1) the ability to reduce the learners' and tutors' uncertainty concerning the accomplishment of the learning process, and (2) the ability to advise the learner on the selection of appropriate learning strategy and materials. This section will briefly describe and illustrate the capability of the Audiographic Learning Facility, as implemented at the present time, to simulate live conversational learning.

Each recorded audiographic learning unit contains as a minimum a graphic-supported narrative presentation on a single, self-contained concept. In addition to this "lesson", the instructor/author may choose to include in the learning unit two other distinct elements: examples, and/or problems. The purpose of the examples is to illustrate the concept presented in the lesson; the purpose of the problems is to test the student's comprehension of the lesson. Each problem will, in addition to the problem statement, contain two items of information: the answer(s) to the problem, and a step by step problem solution. The comprehensive contents of such a learning unit is shown in Figure 7.

In combination with the repertoire of control commands previously described which can be executed by the learner from his terminal or recorded as part of the recording, the Audiographic Learning Facility provides a powerful way for simulating the live learner/tutor interaction. A learner uncertain whether he has grasped the lesson may command the facility in one of three ways, as follows:

1. repeat the lesson;
2. illustrate the lesson by example(s);
3. present the concept covered in that lesson at another level of difficulty or from a different viewpoint (by consulting the directory of learning units and provided, of course, that another presentation is available).

To test whether the student has "learned" the concept presented, the Audiographic Learning Facility presents the student with a narrative/visual statement of a problem, at the conclusion of which it automatically activates the STOP command. The student attempts to derive a solution to the problem, and proceeds then to

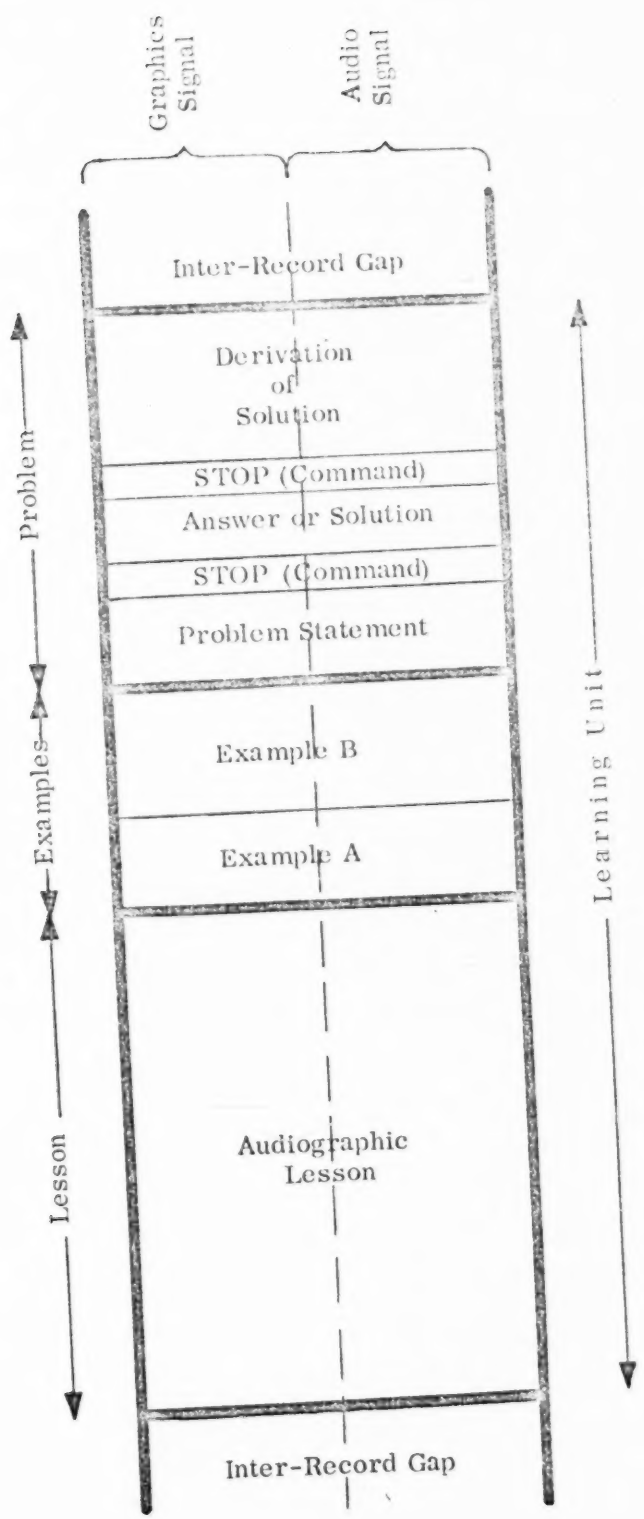


Fig. 7. Contents of a Typical Audiographic Learning Unit

activate the system which responds by displaying the correct result or results. If there is a difference between the answers of the student and the instructor, the student has nevertheless been given a clue and he may again attempt to derive the correct result while the system is in a STOP mode. Whether or not he succeeds, the student can activate the system which then responds by presenting, step by step, the problem solving process or processes through which a correct solution is obtained. Since the exposition of the problem solving process is again in the narrative and graphic form, the instructor can possibly anticipate instances at which individual students might err and recommend at that time appropriate remedial steps. A student who is satisfied that he has grasped and learned the concept presented in the lesson can, of course, skip the examples and problems.

The Audiographic Learning Facility accommodates two types of learning strategy derivations: system implemented under program control, and learner implemented. Its versatility, however, is given principally by the ability of the learner to improve upon and override the linear learning sequence administered under program control. The basis for deriving learning strategies is the logical and semantic structure of the learning materials; the student can obtain learning "directions" with each lesson, either directly from the system and/or from a cross referenced directory of learning goals and units.

The Audiographic Learning Facility differs from computer-aided and programmed instruction systems in that it expects the student to participate in the decision determining the next step in his learning path. It is assumed that the learner, using the partly diagnostic self-testing devices built into and provided by the Facility, is himself able to determine whether or not he has "learned" a particular lesson. In its present stage of development the Audiographic Learning Facility thus assumes a certain amount of intellectual maturity and motivation on the part of the student; and by involving him in the design of his learning strategy it overcomes the passive characteristic inherent in learning systems which depend on automated feedback analysis. The effect of this design philosophy on the simplicity of the Audiographic Learning Facility is considerable: it obviates the necessity for feedback response messages from the learner[1]; and it does not

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[1] In contrast, much information about the student can be gathered by monitoring automatically various parameters of his behavior on the system (learning time, learning paths, etc.). A broad-purpose management software is contemplated for the Audiographic Learning Facility.

require the learner or the instructor/author to employ an artificial language ("CAI language").

A response-recording mechanism can, of course, be provided on the Audiographic Learning Facility in several ways: using the Touchtone telephone terminal for keying coded messages; using the telephone voice channel for audio feedback recording; and using the graphic output device (the telewriter) in its transceiver mode for graphic feedback. This mechanism permits on-line or off-line (delayed) response analysis and/or communication with a live tutor in voice and graphic form. It is intended to combine these response mechanisms in the near future at a moderately powerful level, to be used in conjunction with learners for whom the assumptions of maturity do not hold (e.g., preschool children, disadvantaged learners), and in research.

V. FUTURE WORK

This report has described the objectives and design of a pilot educational facility developed at the School of Information and Computer Science as an operational prototype of a novel category of learning systems. The power of these systems lines in their ability to accommodate concurrently large numbers of learners (when used for group instruction) as well as individual learners; to contain large volumes of educational materials; in their economy of input costs for recording learning materials; in their ability to reproduce the classroom, lecture/blackboard presentation of self-contained concepts whose sequencing and rate of presentation is controlled by the learner and/or the teachers; in their economy of transmission costs; in the 24-hour availability of the learning materials, and the ease of their duplication; and in the mobility of both the terminal and recording apparatus.

As an operational prototype of this catetory of learning systems, the Audiographic Learning Facility is intended initially to provide adequate learning materials for experimental education; to demonstrate the feasibility, operation and use of the system; to provide data for various analyses of the such learning systems; and to provide a base from which to extrapolate the technical design and economics of large-scale systems. These are necessary steps in the research direction outline earlier - that of providing an interface for science information and learning materials. Consequently, the School of Information and Computer Science through its Research Center is committed to a long-term program of research and development in several related directions, as follows:[1]

1. Implementation and Use of the Audiographic Learning Facility

It is intended to bring the Facility, as described in this report, to a full operational status, and to offer through it university-level courses in lieu of traditional (classroom) instruction. Among the tasks underway or contemplated is the development of extended control software, including management programs; the recording of learning materials, and the production of learning aids (e.g., indexes); and the development of administrative policies which shall accompany these changes of traditional education practices.

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[1] Publications reporting on progress in these research efforts are forthcoming.

2. Design of Extended Learning Systems

As a prototype of the category of audiographic, conversational learning systems, the Facility exemplifies only one possible design mode. The School of Information and Computer Science intends to investigate the feasibility and operating characteristics of allied, large-scale systems of this type. Of particular interest are design modes based on the use of digital technology for the storage of audiographic learning materials, in view of the rapidly changing economics of mass storage devices. Another effort currently underway seeks to expand the utility of audiographic learning systems in the education of the blind.

3. Information-Based Research in Learning Process and Systems

Relatively numerous and exciting research avenues are associated with the implementation of the Audiographic Learning Facility. The resource of structured learning materials and monitoring facilities opens up opportunities in studies of human learning, to answer questions which have previously been only posed (e.g., heuristic learning of complex concepts without going through the simple-to-complex-concepts sequence). Studies of semantic information measures and their automatic application in conversational learning systems have been initiated by the faculty of the School. New approaches have been suggested to the study of the key issue of information structure and its physical implementation, directly bearing on the symbiosis of science and education information systems.

Another large category of problems awaiting research involves social aspects and effects of science and learning information systems, ranging from questions of information value to the socio-economics of learning in society. As a developer of a novel learning system, the School of Information and Computer Science must and intends to assume responsibility for a limited, interdisciplinary research effort in this important commitment of the information sciences.

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